ONTARIO SOIL BASELINE SURVEY

ANALYTICAL DATA 1980-1981

VOLUME 1

SOIL BASELINE PROGRAM

A.P.I.O.S. #008/83

Ontario

Ministry
of the
Environment

The Honourable
Andrew S. Brandt
Minister

Gérard J. M. Raymond
Deputy Minister

ONTARIO SOIL BASELINE SURVEY
- ANALYTICAL DATA 1980-1981

VOLUME 1
SOIL BASELINE PROGRAM

TERRESTRIAL EFFECTS PROGRAM
ACIDIC PRECIPITATION IN ONTARIO STUDY

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ONTARIO MINISTRY OF THE ENVIRONMENT
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TABLE OF CONTENTS
(VOLUME 1)

TABLE OF CONTENTS - Continued

ACKNOWLEDGEMENTS

S.N. Linzon, Chairman of the A.P.I.O.S. Terrestrial Effects Working Group originated the concept of the soil baseline program and has guided its development since its inception.

During 1980 and 1981, the collection of soil samples throughout Ontario involved a number of people whose names cannot be individually mentioned here. This work was accomplished under the co-ordination of M.A. Griffith (Southern Ontario), T. Spires (Northeastern Region) and W. Carswell (Northwestern Region). The development of an A.P.I.O.S. soils' laboratory and the chemical analyses of all soil samples were undertaken by the Laboratory Services Branch under the direction of A. Neary. Micom 2001 Word Processing Services typed the tables that form the bulk of Volumes 2 and 3.

Volume 1 of this report was written by M. A. Griffith, A.P.I.O.S., Soil Specialist, Phytotoxicology Section, Air Resources Branch. T. Spires of Northern Terrestrial Consultants and P. Barclay, Lakehead University provided most of the information regarding Northeastern and Northwestern Ontario, respectively. All members of the Terrestrial Effects Working Group's Technical Sub-committee assisted in various editing stages of the report, principally D. Griffin, W. McIlveen and D. Dimma.

SUMMARY

The soil baseline program began in 1980 and is part of the Ministry of Environment's Acidic Precipitation in Ontario Study (A.P.I.O.S.). Over 300 locations were sampled in 1980 and 1981 throughout the province. Soil samples were analyzed at the Ministry's laboratory for pH, texture, iron, aluminum carbonates, major cations, anions and trace metals. A reliable, current and uniform data base for soils across Ontario now exists and is presented in Volumes 2 (Analytical Data for Southern Ontario) and 3 (Analytical Data for Northern Ontario) of this report. This data base is being used by A.P.I.O.S. researchers to design laboratory experiments which will define soil sensitivity criteria. Ultimately, a map will be produced which will show the relative sensitivities of Ontario soils to acidic deposition. Resampling baseline soil profiles over an extended period also provides a means of monitoring trends in soil chemistry due to environmental stress.

This report is mainly a presentation of field and laboratory soil information (Volumes 2 and 3). The major objectives of the soil baseline program and methods used to sample soils are provided in Volume 1. In addition, the glacial history of Ontario, some theories of soil development, and the effect of acidic precipitation on soils are briefly outlined in Volume 1.

SOIL BASELINE PROGRAM

INTRODUCTION

The Acidic Precipitation in Ontario Study (A.P.I.O.S.) was established in 1979 by the Ontario Ministry of the Environment. The objective of A.P.I.O.S. is to protect the Ontario environment from the detrimental effects of acidic deposition, based on study findings. One study task is to determine the effects of acidic deposition on terrestrial ecosystems. The soil baseline program commenced in 1980 as the first phase of the terrestrial study.

Soil data generated in 1980 and 1981, sampling methods used and objectives of the A.P.I.O.S. baseline program are summarized in this report. In addition, some background information on soil-forming theories, soil classification, and the effect of acidic precipitation on soil is provided. The soil data comprise the bulk of the report, also included is general information on Ontario's geology, glacial history, climate and vegetation, all of which interact to produce the soil.

OBJECTIVES

The principal objective of the baseline program is to establish a reliable and uniform data base for soils across the province. This data base 1) provides current data to identify future trends, 2) enables the development of laboratory experiments which define soil sensitivity criteria to acidic precipitation, and 3) provides information required for sensitivity mapping of soils throughout Ontario.

TREND IDENTIFICATION

Baseline data describe the current status of Ontario soils. Trends in soil chemistry are monitored by resampling baseline soil profiles over an extended period. Trends will likely vary across the province, depending on site sensitivity and atmospheric contaminant loading.

Very little historical soil chemical data are available for Ontario. Generally, past soil surveys have been based on aerial photographs and intermittent point checks in the field. Earlier surveys also concentrated on agricultural or managed land, and exact sampling locations are unknown. Because a variety of sampling and analytical methods was used, comparison among different surveys done at different times is unreliable. In contrast, the current A.P.I.O.S. baseline soil sampling is usually restricted to relatively undisturbed soils in areas offering reasonable access and long-term security. The baseline sites are mapped precisely and the analytical methods are documented. Changes found in undisturbed soil may be extrapolated to a similar managed soil. Detailed sampling has been done in the vicinity of A.P.I.O.S. precipitation deposition collectors, with the intention that soil chemistry will be correlated with deposition chemistry.

SENSITIVITY CRITERIA

Once the range and types of soils in Ontario are known, laboratory experiments (e.g. buffering curves) may be designed to rate a soil's sensitivity to acidification. Sensitivity criteria may include soil pH, cation exchange capacity, base saturation, soil depth and texture, presence or absence of carbonate, sulphate adsorption capacity and vegetative cover. Careful, detailed classification of soils allows for extrapolation of these sensitivity criteria to similar soils.

SOIL MAPPING

A data bank obtained by standardized field and analytical methods for soils associated with major landforms is essential prior to mapping soil sensitivity to acidic precipitation. Once sensitivity criteria are developed, they will be applied to the baseline data collected across Ontario. When this relationship is established, a map will be prepared to show the relative sensitivities of Ontario soils to acidic deposition.

SAMPLING METHODS

SITE SELECTION

A.P.I.O.S. baseline soil sites are located on undisturbed soils. Provincial parks, conservation areas and crown land offering reasonable access and long-term security are generally the most suitable for baseline sampling.

Site locations are identified by UTM co-ordinates and a sketch map is prepared in the field showing the sampling location in reference to permanent local features. Sufficient detail is included to permit site relocation. The site is also described according to the guidelines in the Field Manual for Describing Soils.

SAMPLING PROCEDURE

A pit, approximately 1 m^2, is dug to a depth sufficient to permit sampling of the parent material. The soil profile is described according to criteria adopted by The Canadian System of Soil Classification. The soil profile is photographed and a sketch is drawn of one of the faces sampled to show major soil horizon boundaries and the positions of stones, root masses, and sampling points.

Beginning at the deepest horizon, duplicate samples, each approximately 1 kg in weight, are collected with a hand trowel from opposite sides of the soil pit and placed in labelled plastic bags. When sampling is concluded, soil horizons are returned to the pit in the reverse order from which they were removed to achieve the least possible disturbance of the sampling site.

Present plans call for a re-sampling frequency of approximately once every 5 years for baseline sites in Ontario. New soil pits will be dug adjacent to the original pits. To reduce potential effects of seasonal variations on soil properties, repeat samples are collected at the same time of year as the original survey.

SOIL SAMPLE PREPARATION AND ANALYSES

To minimize physical and chemical degradation of the soil, samples are spread out on non-metallic trays and air dried for 48 hours within a few days of collection. Dried samples are disaggregated with a porcelain mortar and pestle or motorized grinder, then sieved to two particle-size fractions: 10 mesh and 100 mesh, ASTM. At least 150 g of the 10 mesh fraction is placed in a glass jar and submitted to the Ministry's Toronto laboratory for analysis. Approximately 5 g is thoroughly ground and passed through a 100 mesh sieve and submitted in a glass vial. This fine, homogeneous sample is easily digested and used for analysis of metals, carbonates, organic carbon and pyrophosphate and dithionite-extractable iron and aluminum. The remainder of the disaggregated sample is stored in cardboard or glass containers of suitable size.

The following analyses are performed on the samples: pH (distilled water and 0.1M calcium chloride); exchangeable calcium, magnesium, potassium, and aluminum; cation exchange capacity; pyrophosphate and dithionite extractable iron, aluminum and manganese; organic carbon; total carbonates; total nitrogen; plant available phosphorus; soluble sulphur, sulphate and aluminum; heavy metals (Cu, Ni, Pb, Zn); and texture (particle size).

DEVELOPMENT AND CLASSIFICATION OF ONTARIO SOILS

HISTORY OF ONTARIO SOIL DEVELOPMENT

Approximately 13,500$^+$ years ago all of Ontario was covered by glaciers (Prest, 1976). As the glaciers advanced, then receded, the variety of landforms common to Ontario today were produced. The history of glaciation is complex and only a simplified account will be presented.

The Laurentide ice sheet which covered Ontario was composed of a number of lobes. Each lobe carried debris from areas far to the northeast or northwest as well as from local sources. The hard bedrock of the Canadian Shield in northern Ontario was stripped of its soil by this ice sheet. Only sterile, polished bedrock plains were left which then received a new cover of shallow till (unstratified deposits of stone, gravel, sand and/or silt) from the glacier.

Much of the original soil on the Canadian Shield was picked up by the advancing glacier and reworked and deposited in southern Ontario as till plains. The glacier often reworked the till to form other features known as moraines (well defined mounds of till) and drumlins (smooth elongated hummocks of till). Glacial meltwater carrying till poured from the edge of the glacier as it receded producing outwash plains. Other fluvial-glacial deposits in Ontario are spillways (channels of old meltwater drainage courses), eskers (snake-shaped ridges of irregularly stratified sand and gravel) and kames or recessional moraines (knobby hills of irregularly stratified sand and gravel).

Ponding of meltwater by the glaciers created lakes where none now exist. The floors of these former lakes and ponds are known as lacustrine plains (clay plain, sand plain). Fragments of glacial lake deposits such as beaches and

shorelines, are still noticeable in Ontario.

Bedrock geology contributes little to direct soil development in Ontario although much of the till which forms the parent material of the soil is bedrock derived. The parent material of Ontario soils is generally the debris deposited by the glaciers or their lakes. There is a broad range of indigenous and exotic plant cover in Ontario. Generally the acidic litter asssociated with coniferous forests enhances podzolization or acidification of soils. Ground vegetation, including lichens and mosses will also affect soil development. Man influences and/or disturbs the development of soils by building roads and urban centres, by felling forests, and by cultivating the land. Atmospheric pollution, including acidic precipitation, may be an additional influence on soil development.

SOIL DEVELOPMENT

A soil consists of layers, known as horizons, of mineral and/or organic matter. These horizons differ in their physical, chemical, mineralogical, and biological characteristics (Joffe, 1949). A soil profile consists of one or more horizons, designated A, B and C starting from the top. Leahey (1961) explains that A horizons contain organic matter derived from plants and organisms. These surface horizons are subject to weathering and leaching of mineral matter more than any other horizon. The B horizon, below the A, accumulates most of the material leached from the A. The C horizon, below the B, represents the relatively unweathered, bedrock or glacial deposits known as parent material. Soils in Ontario vary widely in the nature and thickness of these principal horizons.

As soils develop they often evolve until they reach a slowly changing state. Their development is governed by five main factors: parent material, climate, organisms, topography, and time. The important characteristics of each factor are summarized from Fitzpatrick (1972) and Buol et al (1973).

Parent Material

Parent material is the initial state of the soil system (Jenny, 1941). It is composed of mineral material and/or organic matter. Most of the parent material in Ontario are glacial deposits or water-laid sediments (lacustrine). The nature of the parent material is largely responsible for the course of soil formation and the resulting chemical, mineralogical and physical composition of the soil. Many features of the soil are directly related to soil parent material, such as, mineral stability, particle-size, degree of sorting, formation of clay minerals and permeability.

Climate

Climate, through temperature and precipitation, is the principal factor governing the type and rate of soil formation. Temperature affects the weathering of soil minerals, the rate of biological activity within the soil, the decomposition of organic matter and water evaporation from the soil. Moisture entering the soil is derived mainly from precipitation. The differentiation of horizons is largely determined by the movement of moisture in soil and subsequent chemical reactions. Some moisture is retained by the soil but most is lost through drainage or evapotranspiration.

Organisms

Soil and vegetation develop concurrently. Vegetation adds organic matter or litter to the soil surface. Deposits of coniferous needles beneath the tree contribute to local soil acidity while deciduous foliage provides a more base-rich litter. In addition, vegetation cycles and exchanges nutrients with the soil, binds the soil to prevent erosion, and alters the initial form and structure of the soil.

Burrowing mammals and worms mix the soil . Microorganisms such as bacteria, actinomycetes, algae and fungi participate in elemental cycling, production of organic matter, and transportation of material throughout the soil.

Topography

The initial shape, slope and orientation of the landscape is governed by local topography. Drainage patterns, amount of moisture, soil distribution and thickness, and vegetation types are also affected by topography.

Time

Soil formation is a very long and slow process. Surface horizons may take only a few hundred years to form, while those derived from weathering of primary minerals may take thousands of years to develop (Birkeland, 1974).

SOIL CLASSIFICATION

Soils in Ontario are grouped into the following orders: Podzolic, Brunisolic, Luvisolic, Regosolic, Gleysolic and Organic (Figure 1). These groups are based on the properties and arrangement of soil horizons within a soil profile. They result from major differences in climate, vegetation, topography, parent material and time. The soil orders may be further divided into Great Group and Subgroup.

The following descriptions of the soil orders are summarized from Ontario Soils (1975), Soils of Canada (1977), and The Canadian System of Soil Classification (1978).

Podzolic soils are usually found in cold to temperate climates on acidic parent materials. The LFH horizon is thin (1 to 3 cm) and is composed of organic materials such as tree litter (L), partially decomposed residues (F), and residues in an advanced stage of decomposition (H). The Ae horizon is a gray leached layer, which is often; but not always, present. The B horizon represents a layer which accumulates iron (Bf) and organic matter (Bh).

The surface horizon of Brunisolic soils is a mineral layer mixed with organic materials (Ah). Under cultivation, this horizon is termed an Ap layer. Ae horizons can also occur. The B layer is weakly developed (Bm). It lacks a marked accumulation of organics, iron or clay and/or is less than 10 cm thick.

The surface horizon (Ah) of Luvisolic soils is enriched with organic accumulations. The Ae horizon is grayish brown due largely to the eluviation of clay and organic matter. A Bt horizon indicates that accumulation of clay is great enough to be significantly different from the Ae.

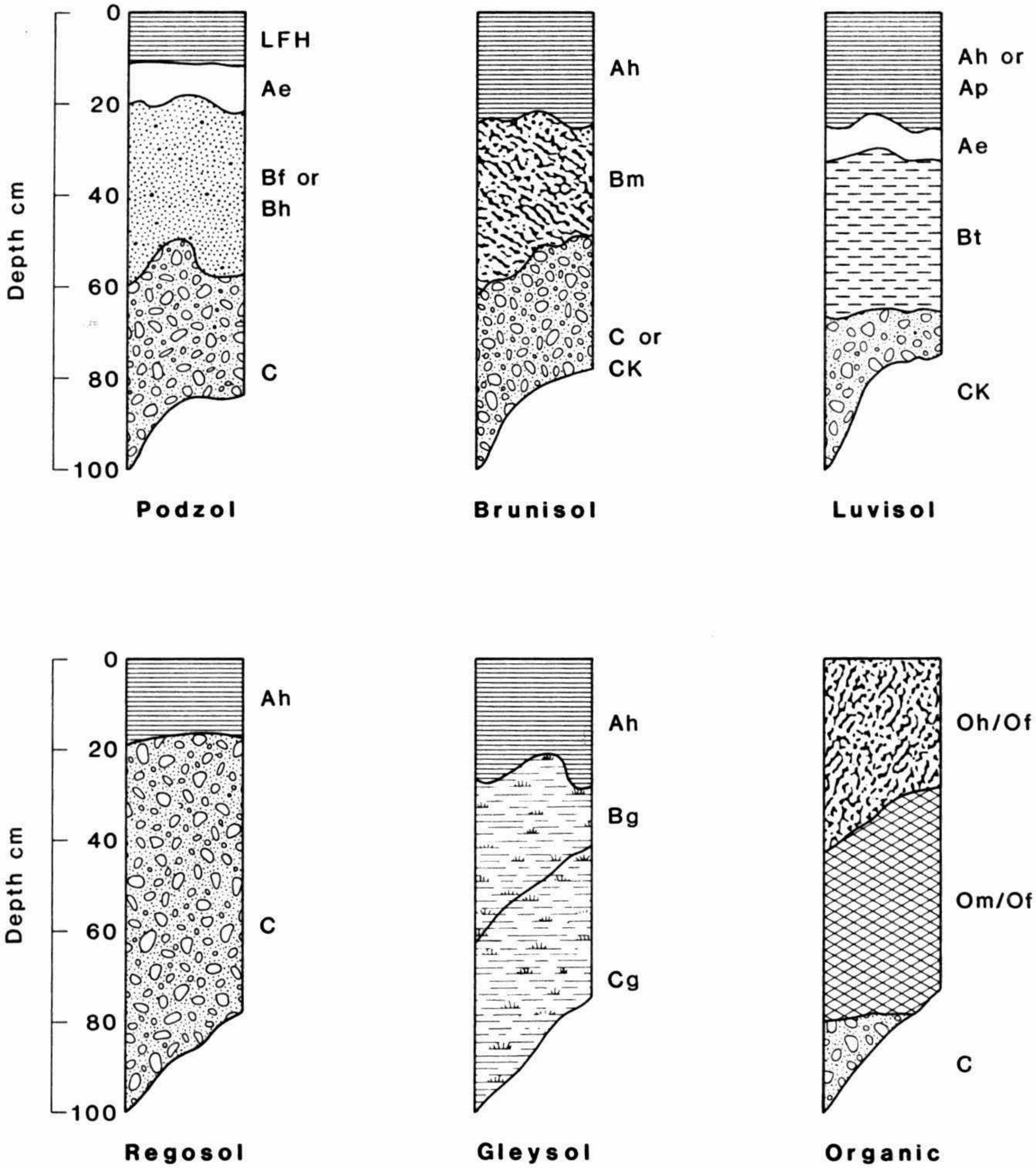


FIGURE 1: TYPICAL PROFILES OF SOME ONTARIO SOILS.

Regosolic soils lack a B horizon but may have a mineral-organic surface layer. Regosolic soils essentially reflect the characteristics of the C horizon or parent material.

Gleysolic soils are saturated with water during some period of the year and are subject to reducing conditions. These drainage conditions result in a soil profile with varying degrees of mottling (Ag, Bg, Cg). The bright red, orange and yellow mottles are usually oxidized iron compounds.

Organic soils are developed from accumulations of organic materials, such as grasses, reeds, rushes, sedges, mosses and trees. Organic soils vary in their stage of decomposition, a characteristic often used in their classification. These soils are saturated with water most of the year.

EFFECTS OF ACIDIC PRECIPITATION ON SOILS

Acidic deposition comprises all acidifying components deposited from the atmosphere as a result of man-made and natural activities. Sulphur dioxide and oxides of nitrogen undergo complex chemical reactions in the atmosphere to form acidic substances. These acids can be transported over extremely large distances but eventually fall to the ground as dry or wet deposition.

The effect of acidic precipitation on soil is potentially significant because the soil is the reservoir of plant nutrients. Also, soil, where present at sufficient depths, is the source of much of the water for aquatic systems. Changes in the soil's chemistry may therefore be reflected in the aquatic environment.

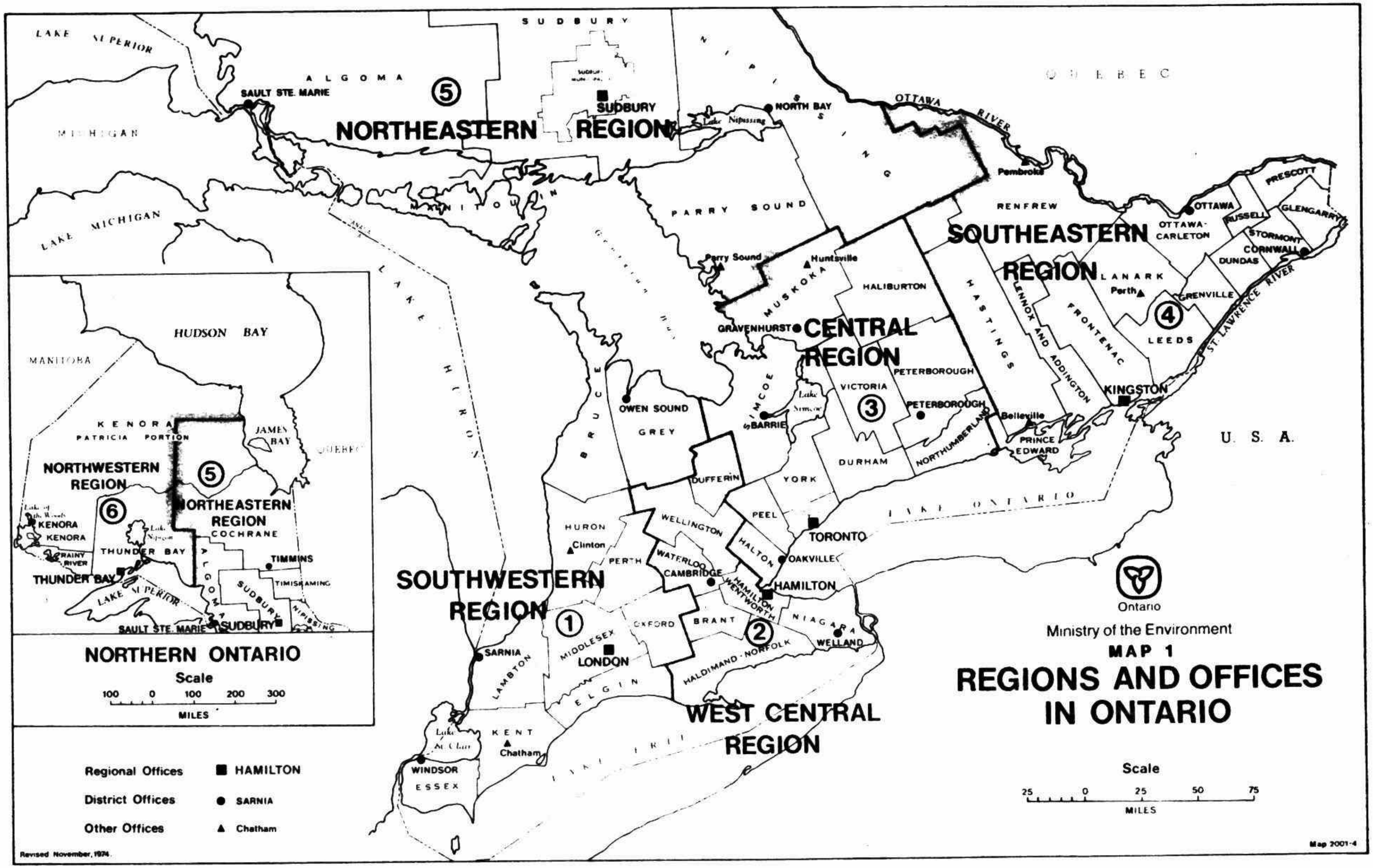
The effect of acid inputs on the environment depends on the quantity and acidity of atmospheric inputs, and the buffering capacity of the terrestrial and aquatic ecosystems. Information on the effects of acidic precipitation on soils is available from effects near point sources of pollution, from experimentation with simulated rain solutions, from natural changes observed in soil over time, and from models and soil forming theories. Anticipated effects of soil acidification include: reduced pH, leaching of basic cations (such as magnesium and calcium), and other exchangeable plant nutrients, reduction in base saturation and cation-exchange capacity, mobilization of soil-bound metals such as aluminum, and changes in biological activity such as decreased nitrification and soil respiration (Bache, 1980).

THE SOIL FORMING ENVIRONMENT IN ONTARIO

A brief description of the bedrock and glacial geology (Chapman and Putnam, 1976; Boissonneau, 1966, 1968 and Prest, 1976), vegetation regime (Hosie, 1979), climate (Brown, et al, 1980; Chapman and Thomas, 1968) and man's influence on the soil environment are included in the following section , along with comments about soil sensitivity to acidic precipitation.

Maps depicting the physiographic features for each of the Ministry's six regions of Ontario (Map 1) with the location of A.P.I.O.S. precipitation stations and baseline soil pits are provided. It is not feasible that all the landforms in Ontario could be shown on this small a scale. Most of the major physiographic features, however, are illustrated. Detailed soil sampling was done at two A.P.I.O.S. sites at Dorset, in Central Region (Plastic Lake, Blue Chalk Lake) and near A.P.I.O.S. experimental vegetation plots in the Northeastern Region.

The soil analytical data appear in separate volumes of this Report. Volume 2 contains the analytical data for Southern Ontario while Volume 3 contains the analytical data for Northern Ontario. The classification of the soils and their associated horizons follows the guidelines of The Canadian System of Soil Classification (1978). At some sites, classification was based on field observations in conjunction with chemical information. Thin horizons, particularly the LFH and Ae, proved to be difficult to sample without some contamination from adjacent horizons. Occasionally, a soil profile could be placed in two or more different soil types based on available chemical data alone. In these situations field observations supplied essential information for final classification decisions.


SUDBURY
LAKE SUPERIOR
ALGOMA
SAULT STE. MARIE
⑤
NORTHEASTERN REGION
SUDBURY
MICHIGAN
NORTH BAY
Lake Nipissing
NIPISSING
OTTAWA RIVER
QUEBEC
Pembroke
MANITOULIN
LAKE MICHIGAN
PARRY SOUND
RENFREW
OTTAWA
PRESCOTT
RUSSELL
GLENGARRY
OTTAWA-CARLETON
SOUTHEASTERN REGION
STORMONT
CORNWALL
DUNDAS
Parry Sound
Huntsville
MUSKOKA
HALIBURTON
HASTINGS
LENNOX AND ADDINGTON
FRONTENAC
LANARK
Perth
GRENVILLE
④
ST. LAWRENCE RIVER
LEEDS
LAKE HURON
GEORGIAN BAY
GRAVENHURST
CENTRAL REGION
HUDSON BAY
MANITOBA
PETERBOROUGH
VICTORIA
③
PETERBOROUGH
KINGSTON
SIMCOE
Lake Simcoe
BARRIE
OWEN SOUND
GREY
BRUCE
Belleville
PRINCE EDWARD
NORTHUMBERLAND
DURHAM
U. S. A.
KENORA
PATRICIA PORTION
JAMES BAY
QUEBEC
NORTHWESTERN REGION
⑤
NORTHEASTERN REGION
⑥
KENORA
COCHRANE
THUNDER BAY
TIMMINS
RAINY RIVER
ALGOMA
THUNDER BAY
TIMISKAMING
SUDBURY
LAKE SUPERIOR
NIPISSING
SAULT STE. MARIE
SUDBURY
DUFFERIN
YORK
PEEL
TORONTO
LAKE ONTARIO
WELLINGTON
HURON
Clinton
PERTH
WATERLOO
CAMBRIDGE
HALTON
OAKVILLE
HAMILTON
HAMILTON-WENTWORTH
SOUTHWESTERN REGION
①
MIDDLESEX
OXFORD
BRANT
②
NIAGARA
WELLAND
LONDON
HALDIMAND-NORFOLK
SARNIA
LAMBTON
ELGIN
NORTHERN ONTARIO
Scale
100 0 100 200 300
MILES
WEST CENTRAL REGION
KENT
Chatham
Lake St. Clair
WINDSOR
ESSEX
LAKE ERIE
Regional Offices ■ HAMILTON
District Offices ● SARNIA
Other Offices ▲ Chatham
Ontario
Ministry of the Environment
MAP 1
REGIONS AND OFFICES IN ONTARIO
Scale
25 0 25 50 75
MILES
Revised November, 1974.
Map 2001-4

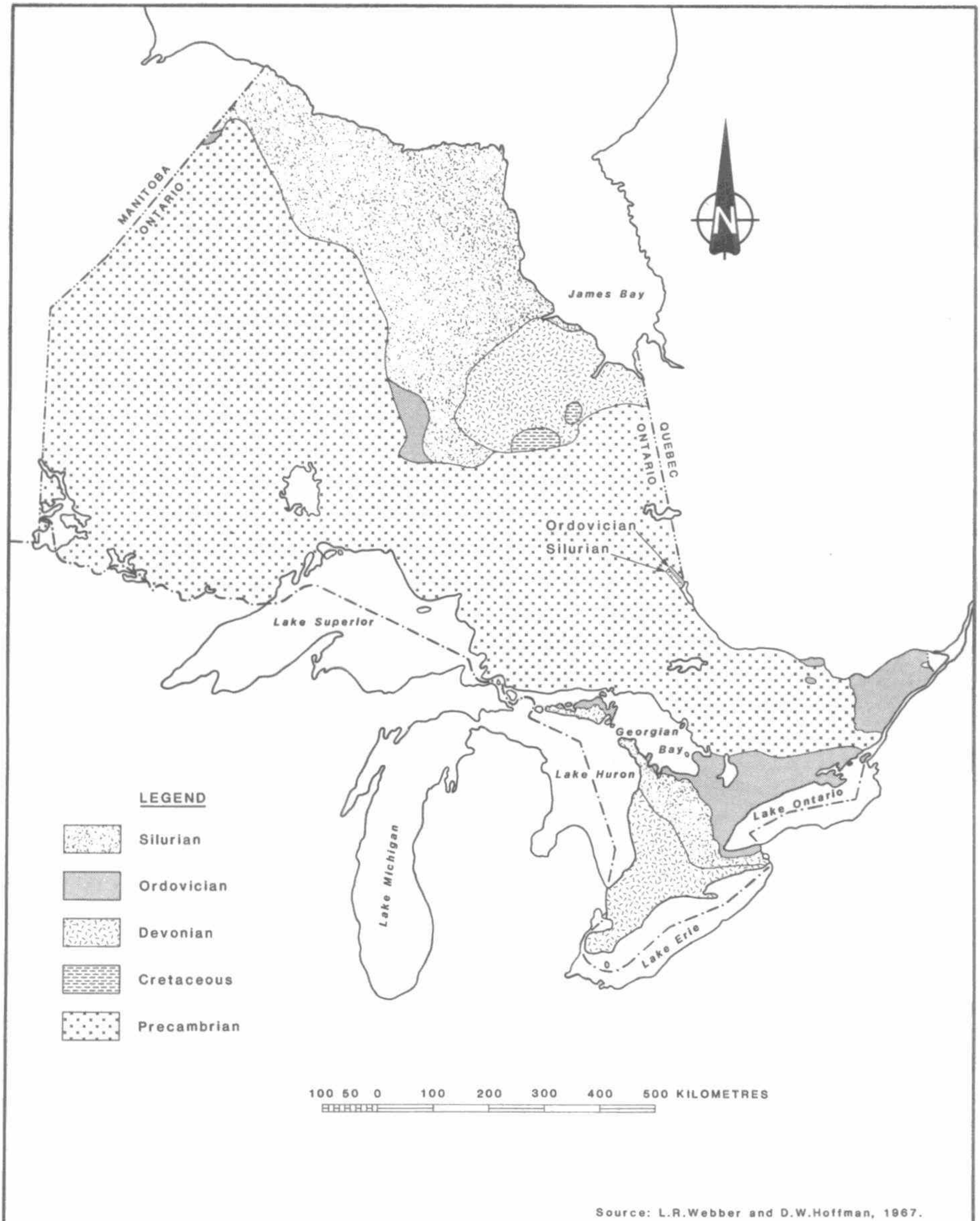
SOUTHWESTERN REGION

The Paleozoic bedrock in this region is flat-lying marine sedimentary shale and limestone of mainly Devonian age (Map 2). Some Silurian age dolomites and limestones occur in the north. The entire area was glaciated and thick deposits of till and lacustrine material were deposited over the bedrock and form the parent material of the present-day soils. Most of the material was probably transported only a short distance, since the majority of rock fragments produced exhibit characteristics similar to the local bedrock. The glacier left many different types of parent materials which produced a region with diverse local physiography (Map 3).

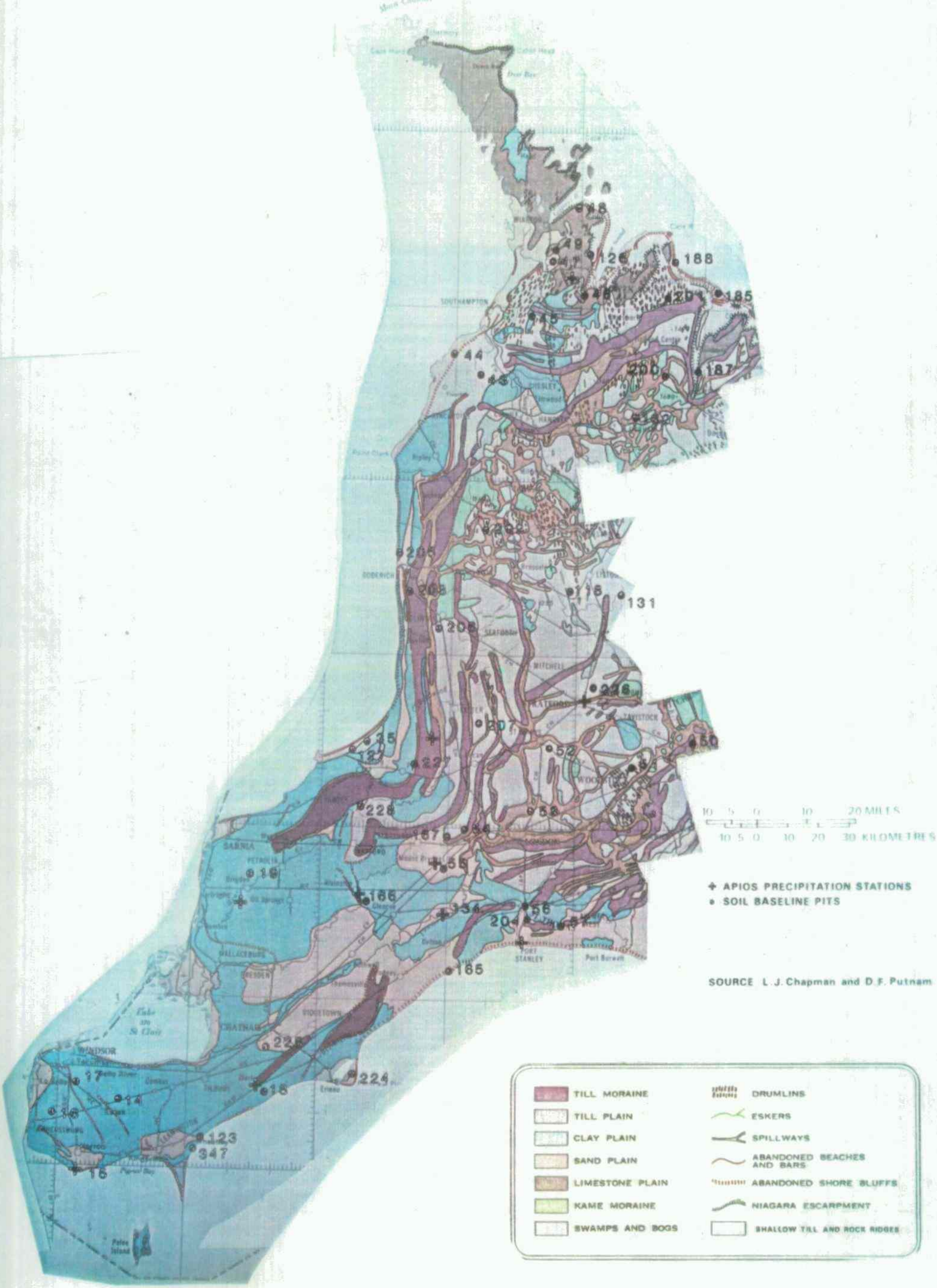
The till plain between Lake Erie and Lake St. Clair was smoothed by stages of Lake Erie during glaciation. Little relief produced poor soil drainage and Gleysolic soils. The sand plains directly east were once deltas of the Thames River and glacial Lake Warren, another stage of Lake Erie. The sandy Brunisols of these plains are acidic and very deep.

Along the eastern edge of Lake Huron is a clay plain over calcareous till. Interspersed with the clay plain are two beaches and wave-cut terraces with boulders, gravel bars and sand dunes. This strip of Luvisolic and Brunisolic soils is poor for agriculture and much of the farmland has been abandoned.

Further inland from Lake Huron are calcareous till plains, moraines, spillways, some eskers and drumlin fields. Swamps and bogs occur in depressions.



MAP 2: THE BEDROCK GEOLOGY OF ONTARIO.



MAP 3 PHYSIOGRAPHY OF SOUTHWESTERN ONTARIO AND APIOS BASELINE SOIL PITS.

The Bruce Peninsula in the north of the region is generally a zone of glacial scour. Apart from some silt beds and a few drumlins, gravel bars and sand dunes, there is little overburden scattered over the gray dolomite. The Regosolic soils are very shallow and limestone bedrock is often exposed.

Large water bodies greatly modify both the temperature and amount of moisture in this region. This is the warmest area of Ontario and soils may be actively formed for approximately 6-8 months of the year. Precipitation is fairly uniform during the year. The amount of precipitation ranges from 77 cm in the southwest to 97 cm at the eastern edge of the region to the lee of the Niagara Escarpment. The mean duration of snow cover ranges from 50 days near Windsor to 124 days north of London.

The natural forest vegetation (Hosie, 1979) is deciduous in the extreme south. The rest of the region is in the Great Lakes-St. Lawrence mixed forest. Most of the land, has been deforested and used for agriculture at least once.

Pockets of soil that are potentially sensitive to acidic precipitation exist in this region. The acidic sand plains along Lake Erie are one example. Generally the clay soils of this region, although often slightly acidic in the top horizon, possess some degree of buffering ability due to their texture. The sand and gravel soils of the till plains may also be acidic at the surface but the C horizon or parent material is usually calcareous and therefore strongly buffered. Ground-water runoff from these soils will likely not be acidic.

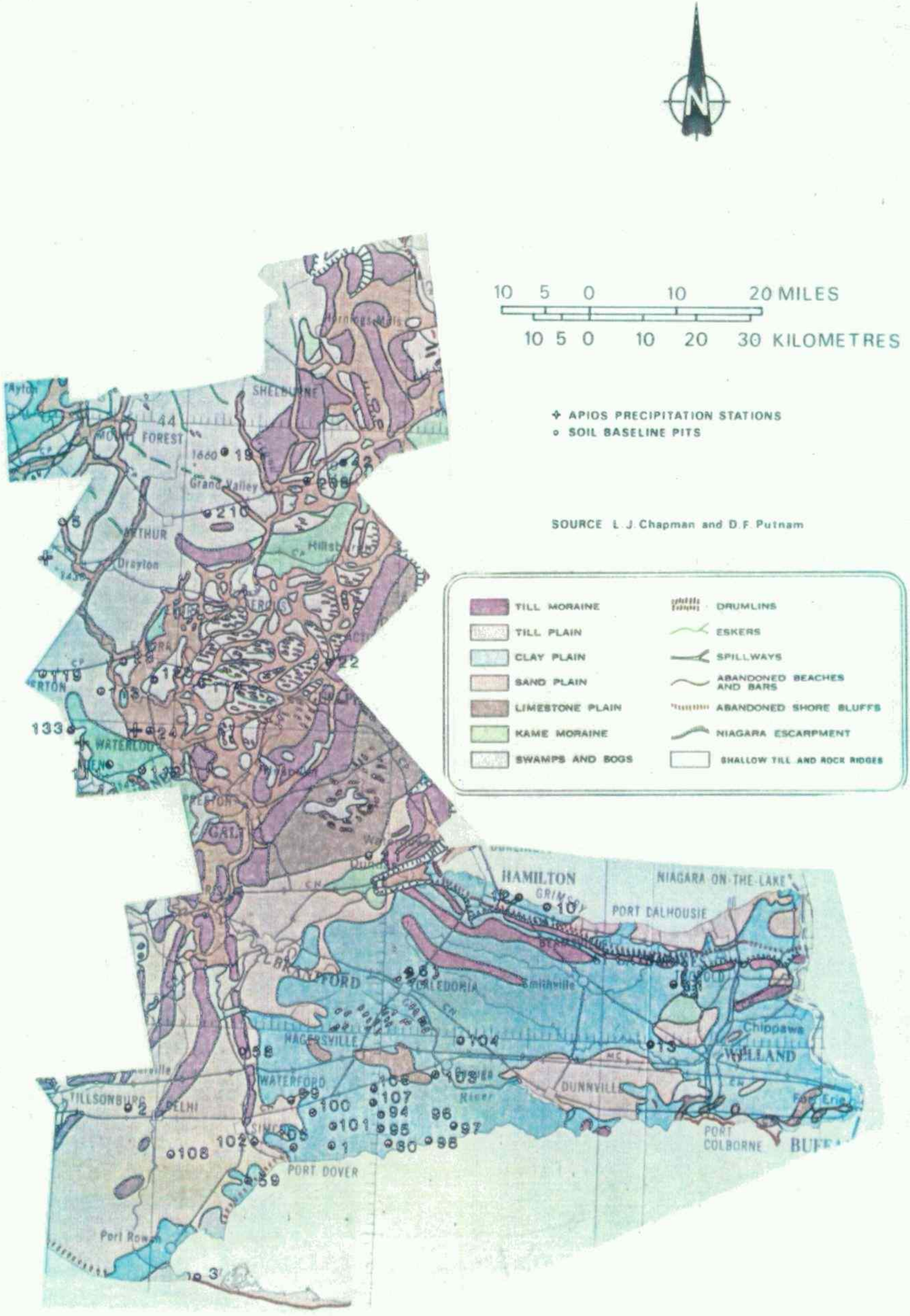
WEST CENTRAL REGION

Most of the region is underlain by Silurian dolomite and shales and Devonian limestones (Map 2). Rapidly weathering Ordovician shale borders the eastern perimeter.

The topsoil of the sand plain in the southwest is easily windblown and poorly buffered. It was once a delta formed by glacial Lakes Whittlesey and Warren. An extensive clay plain rich in silt lies between Lakes Ontario and Erie. These Luvisolic soils were originally deposited by the lakes then reworked by glaciers. Lacustrine beaches, wave-cut terraces, gravel bars and spits are associated with glacial Lake Iroquois between the escarpment and present Lake Ontario (Map 4).

Calcareous till covers the rest of the region to the north. Brunisols are most abundant but Luvisols and Regosols are also common. The terrain often is hilly, with morainal deposits, eskers, gravel outwash plains, and sandy kames. Deep gravelly spillways run between fields of calcareous drumlins. Swamps and peatbogs are common in low lying areas throughout the entire region. Organic and Gleysolic soils are associated with these wet areas.

The proximity of this area to the Great Lakes greatly modifies the climate. Frost-free days range from 180 in the south to 120 in the north. The average amount of precipitation is 82 cm for the region. The mean duration of snow cover ranges from 75 days in the south to 125 in the north.



MAP 4 PHYSIOGRAPHY OF WEST CENTRAL ONTARIO AND APIOS BASELINE SOIL PITS.

The natural forest vegetation (Hosie, 1979) is deciduous in the south bordering Lake Erie and the western tip of Lake Ontario. The rest of the region is covered by a Great Lakes - St. Lawrence mixed forest. The region was settled early and deforested. More recently, there has been rapid urban expansion. As fields are now more prominent than forests, thicker Ah horizons might be expected in the soil.

Although the till at depth is mostly calcareous, the soils which develop on them are often acidic at the surface. In time, acidic precipitation could intensify the acidic nature of the soils and lower the level of the "Ck" horizon. The deltaic sands in the south along Lake Erie are already quite susceptible to the loss of plant nutrients due to acidic precipitation. These soils have little organic matter and little or no natural buffering capacity.

CENTRAL REGION

Silurian shale and limestone border this region to the west. Ordovician shale and limestone bedrock parallel the Silurian rock to the east. Ordovician limestones underlie the majority of the region to the east and north. All of Haliburton, Muskoka and the northern portions of Victoria and Peterborough counties are comprised of Precambrian bedrock (Canadian Shield) (Map 2). It is not uncommon to find large areas of exposed bedrock in this zone.

A narrow, gravelly calcareous shoreline of glacial Lake Iroquois runs parallel to Lake Ontario. Cliffs, beaches, bars and boulder pavements typify the area (Map 5). These lacustrine deposits are generally Luvisols and Brunisols.

A partially drumlinized till plain exists to the north. The till and its associated moraines, drumlins, eskers, and kames are subject to erosion by gullying. Small calcareous clay plains in the area are remnants of temporary glacial ponds or lakes. Luvisolic soils are associated with these clay plains.

North of the till plain are end moraines or kames. The land is subject to erosion. Aeolian (wind-blown) material occurs in pockets throughout the area. Along the northern edge of these end moraines are deep deposits of stratified (varved) lacustrine sediments. The hilly relief of the drumlinized till plain under these lacustrine clays and silts is often evident. There are thousands of highly calcareous drumlins and some gravelly eskers in this till plain near Peterborough. Clay may be found between the drumlins which were likely flooded by glacial lakes.

MAP 5 PHYSIOGRAPHY OF CENTRAL ONTARIO AND APIOS BASELINE SOIL PITS.

Pockets of deltaic sands and bogs are quite common between Lake Simcoe and Georgian Bay. The till here is formed more from granitic bedrock than limestone. The Brunisolic and Podzolic soils vary from mildly acidic and therefore potentially sensitive to acidic precipitation, to calcareous.

The Shield area, in the northern part of the region, comprises shallow, sandy till and rock outcrops. Noncalcareous sand deposits from Lake Algonquin (Lake Huron, Georgian Bay) are found in this area. There are a few clay plains which are remnants of inland lakes or ponds. Spillways and some moraines are also evident. The noncalcareous sands of the Podzols and Brunisols provide little buffering capacity.

The proximity of this region to Lake Ontario in the south and Lake Huron to the northwest has a moderating effect on the climate. Annual precipitation is fairly uniform, 81-86 cm across the region. Even so, the clay soils are often deficient of moisture in the summer. Along the Lake Ontario shoreline frost-free periods are 1 to 2 months longer (180 days) than inland (120 days). Colder winters and later springs in the north can inhibit soil development.

The region has been so heavily urbanized in the south that little indigenous forest vegetation is left. A narrow band of deciduous forest (mainly birch, maple, black walnut, hickory and oak) occurs along Lake Ontario. The rest of the region is covered by the Great Lakes - St. Lawrence Forest, featuring red pine, eastern white pine, eastern hemlock, yellow birch, maple and oak (Hosie, 1979).

Urbanization, industrial expansion and agriculture have disturbed the natural development of soils in this region. Generally, however, in the till

covered areas of the south the parent material of the Brunisols and Luvisols is calcareous. This calcareous material provides considerable buffering at depth against acidic precipitation inputs. Water moving from the soil to aquatic systems should be mostly alkaline. Carbonate has been found to leach out of the upper horizons of the soils in a cool humid climate. In time, the soil may become acidic. The leaching of cations may be a natural phenomenon but could also be accentuated as rain pH decreases.

The sandy, often thin deposits of poorly to moderately buffered Brunisols and Podzols on the Canadian Shield, have the potential to be affected by acidic precipitation, with possible adverse effects on surrounding aquatic and forest ecosystems.

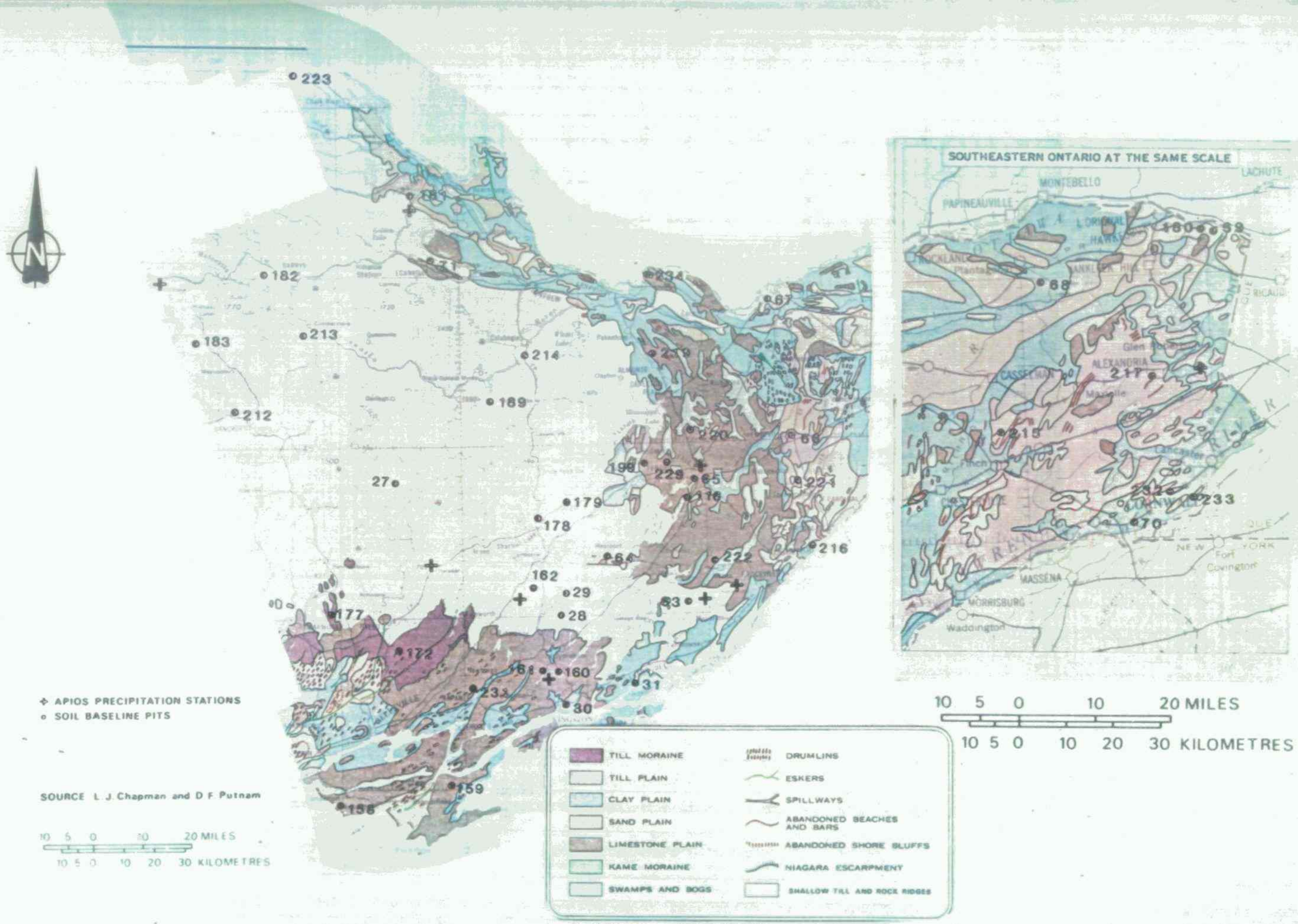
SOUTHEASTERN REGION

The bedrock in the southwest of this region is Ordovician limestone while Precambrian Shield predominates to the north and east. Ordovician sandstones and dolomite occur farther east. The remainder of the region is underlain by different ages of Ordovician shales and limestones (Map 2).

There are areas of active sand dunes and shallow, stoney till in the south (Map 6). Inland, a limestone plain continues to the north and east bordering Lake Ontario. The land is rough and stoney with both limestone and Precambrian Shield rock fragments in the moraines. There are sand and gravel-rich spillways and eskers and a drumlin field. Numerous clay plains occur interspersed over the limestone plain with some sand and gravel shorelines. The slightly calcareous clay plains were formed from freshwater glacial lakes and/or from the marine water of the Champlain Sea. According to Fairbridges (1968) the Champlain Sea formed when the glacier receded to the north of Lake Iroquois and admitted water from the Atlantic Ocean. The sea covered approximately 530,000 sq km in Ontario and Quebec.

The hilly northern portions of the region have thin, sandy, soils with numerous Precambrian rock outcrops. These Podzols and Brunisols are predominantly acidic in nature. Spillways and sand plains, which are remnants of glacial Lake Iroquois, as well as bogs and swamps, are scattered throughout this part of the Shield.

East of the limestone plain and south of the Shield, the topography is very hilly. Hills of Precambrian Shield rock protrude out of clay left from the Champlain Sea. The clay is slightly calcareous. Bogs are scattered throughout



MAP 6 PHYSIOGRAPHY OF SOUTHEASTERN ONTARIO AND APIOS BASELINE SOIL PITS

the area. The Podzols and Brunisols are acidic where drainage is good. Gleysolic soil exists in poorly drained areas.

There is an area of level glacial-fluvial sands to the east of Leeds County. The sands were spread out over bedrock and clay by the wave action of the Champlain Sea. As well as beach ridges and sand dunes, some glacial moraines are still evident. This flat area is poorly drained and there are many bogs. The soils are usually gleyed. Although the parent material has some carbonates, these poorly developed soils are mainly acidic.

A low plain bordering the St. Lawrence River to the east of the sands contains drumlins and drumlinoid features. This plain was covered by the Champlain Sea and there are still some clay flats and sand and gravel beaches remaining. North of the till plain is a low, flat, clay plain with the till protruding through in spots. This area is poorly drained and the soils are gleyed.

A large level sandplain to the north was once a delta built by the Ottawa River. This poorly drained soil is 5-10 meters deep and low in carbonates. Stoney hills of calcareous till protrude through the sand intermittently. The gleyed Brunisols are generally quite acidic. Bogs are also common in this poorly drained area.

There is a wide range in frost free days, in response to the influence of Lake Ontario in the south and increasing altitude to the north. There are 160 frost free days in the south, compared to only 120 in the north of the region. Precipitation amounts vary as well, with an average of 86 cm in the south and 66 cm in the north, near Pembroke.

The Great Lakes-St. Lawrence Forest region covers the entire region. The principal tree species are red pine, eastern white pine, eastern hemlock, yellow birch, maple and oak. The region was settled in the late 1700's in the south and mid-1800's in the north. Most of the forest was removed for lumber and to prepare the area for agriculture.

The bedrock and parent material in the south is slightly calcareous. However, the cool, humid climate in conjunction with coniferous vegetation moves the soil towards natural acidic conditions by the leaching of bases. Although runoff may be acidic at the soil surface, it will likely be buffered, prior to reaching streams and lakes, where the bedrock and/or parent material is calcareous. The acidity at the soil surface may be altered by acidic precipitation inputs and have an effect on vegetation. The sand plain in the east of the region is not calcareous and both aquatic and vegetation ecosystems could be affected by acid precipitation where the underlying limestone bedrock is not in contact with runoff. The soils of the Shield area are shallow, naturally acidic, and the bedrock offers very little buffering. Therefore, both aquatic and forest ecosystems are potentially sensitive to acidic inputs on the Shield.

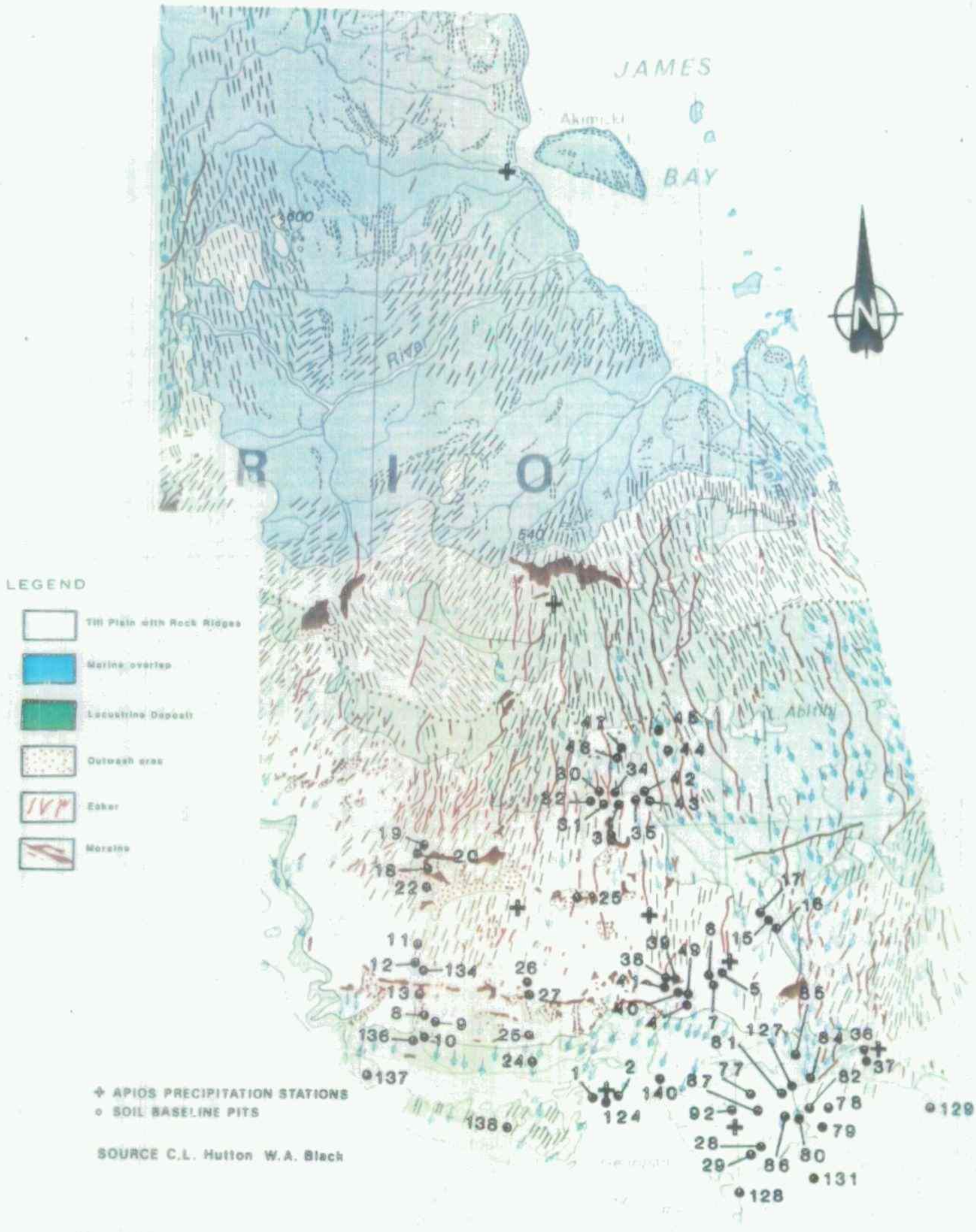
NORTHEASTERN REGION

In many parts of Northeastern Ontario bedrock is either exposed or is close to the surface. The area consists mainly of Precambrian igneous and metamorphic bedrock. Precambrian sedimentary deposits predominate in the eastern part of the region and along the north shore of Lake Huron. Volcanic rocks are also common throughout this area. Ordovician and Silurian limestones are found near James Bay. These limestones have had considerable influence on the soil chemistry of Northeastern Ontario. Limestone bedrock is also present in the New Liskeard area and on Manitoulin Island (Map 2).

According to Boissoneau (1966, 1968), a glacial lake (Lake Algonquin) was formed in the upper Great Lakes basin more than 11,000 years ago. Glacial meltwaters carrying suspended material flowed into this lake and these materials were deposited as the clay plains and sand deltas found in the southern part of the Northeastern region (Map 7).

A sandy glacial till was deposited in those areas not influenced by glacial lakes. However, as the ice front retreated, other glacial lakes were formed. The largest of these is known as Lake Barlow-Ojibway. Carbonate-rich clays and silts were deposited in this lake to form the area now known as the Northern Clay Belt. Sands were deposited in smaller lakes near Chapleau and to the east of Gogama.

In the southern part of notheastern Ontario, Podzols and acidic Brunisols have developed on the large areas of sandy tills and lacustrine sands. Brunisols, Gleysols, Luvisols and organic soils are present in areas of lacustrine clays and silts. Except for organic soils many of these soils contain substantial amounts of carbonates.



MAP 7 PHYSIOGRAPHY OF NORTHEASTERN ONTARIO AND APIOS BASELINE SOIL PITS.

The climate of northeastern Ontario is modified by both the Great Lakes and James Bay. The mean annual precipitation varies from 65 cm in the north, to 86 cm in the south and mean annual temperature, from $+1^{o}C$ to $+4^{o}C$.

The Great Lakes-St. Lawrence forest type predominates in the area bordering the Great Lakes. Red pine, eastern white pine, eastern hemlock, yellow birch, maple and oak are all found in this area. The Boreal forest covers the rest of the region. White spruce, black spruce, balsam fir, jack pine, white birch and trembling aspen dominate the middle of the region while white spruce, black spruce, tamarack and large unforested areas occur in the exterme north.

Although most of the soil orders common to Ontario are represented in this region the majority of the soils are Podzolic or acid Brunisolic. Luvisolic soils are assoicated with glacial lake beds such as the Northern Clay Belt. The sandy Podzols and Brunisols are more sensitive to acidic precipitation than the clay-rich Luvisols.

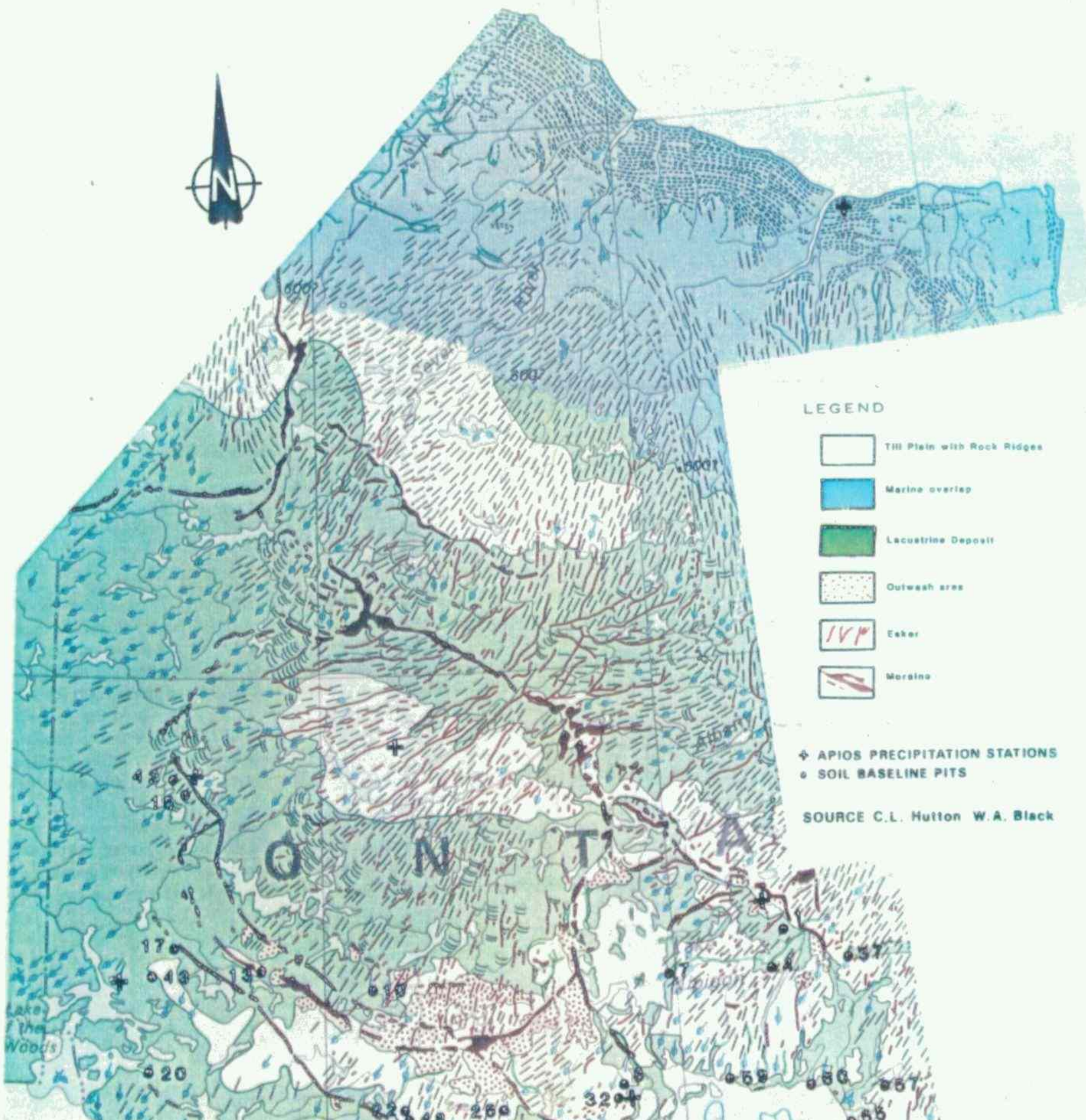
NORTHWESTERN ONTARIO

The Precambrian Shield is the major geological unit in the region and is made up of mostly igneous and metamorphic bedrock. Bedrock formations of Silurian and Ordovician limestones, sandstones, siltstones and shales occur in a block bordering Hudson Bay (Map 2).These rocks are generally high in carbonates and therefore have high buffering capacities.

The ice began retreating from southern parts of this region about $12{,}500^{+}$ years ago and some ice may have been present in northern areas as late as $5{,}000^{+}$ years ago (Prest, 1976). The entire area, therefore, has been much affected by glaciation and the effects are obvious (Map 8). These include exposed bedrock and other areas covered by glacial till and various water lain materials.

The area adjacent to Hudson Bay was scoured and abraded by the glacier and depressed by the weight of the ice. When the ice sheets receded this area was inundated by the Tyrell Sea for several thousand years. This has resulted in a mostly flat plain covered with marine deposits of clay, silt, sand and gravel. Other features include moraines, eskers, and even raised beaches as far as 270 km inland. Many of these glacial and marine deposits are derived from the sedimentary bedrocks of this area and have a high cation exchange capacity.

Once the glacier began to recede, large temporary freshwater lakes were formed. These glacier-fed lakes were present in this region for a period of about 4,000 years, from about 12,000 to 8,000 years ago. Lake Agassiz was formed in the west, and Duluth-Minong-Houghton Lakes in the Superior Lake



MAP 8 PHYSIOGRAPHY OF NORTHWESTERN ONTARIO AND APIOS BASELINE SOIL PITS.

Basin in the centre. These lakes resulted in various features such as raised beaches, sand and gravel ridges and wave-cut bluffs. More importantly, however, are the large lacustrine deposits of sand, silt and clay that have resulted in flat areas sometimes suitable for agriculture (at Thunder Bay, Dryden, and Fort Frances) and which also produced some of the better forest soils. Extensive aeolian (wind blown) deposits of fine sands and silts also are present in areas such as Lac des Mille Lac, northwest of Thunder Bay. Considerable areas of organic peat soils have been deposited in poorly drained areas of the Shield.

The climate of the Northwestern region is continental. It is modified in the north by Hudson Bay and in the south by Lake Superior. In the coldest month, January, the temperature isopleths run from west to east and the mean daily temperature varies from -25°C in the north to -13°C in the south. In July, the warmest month, the trend is not north to south, but northeast to southwest, and in the northeast the mean is 12°C increasing to 19°C in the southwest. The area has cold winters and cool to warm summers. Precipitation patterns are more complex, with the lowest precipitation in the northwest (32 cm) and the highest in the southeast (90 cm). Most precipitation occurs as rain, but about one-third to one-half may fall as snow. The lowest mean maximum snow depths, 32 cm, are in the west, while the greatest, 76 cm, are in the east.

There is a gradient of vegetation in the region from almost treeless, tundra-like vegetation on the shores of Hudson Bay to a well developed, mixed conifer-deciduous forest in the south. Soils, while very important in the local distribution of plants, are seen as less important than climate on a larger scale. In the south of this region the Great Lakes-St. Lawrence Forest association is most prominent. It contains a number of hardwood tree species not found in the

Boreal forest such as sugar maple, Manitoba maple, bur oak and much more white elm, black ash and red maple than are found to the north. The Boreal conifer forest predominates in the centre of this region. This forest is a dynamic successional forest resulting from forest fires, which occur about every seventy to one hundred years, and more recently from logging. Various patterns develop after fires and logging, which produce an enormous mosaic of different-aged stands with different species compositions. Generally, though, black spruce is the dominant tree on thin acid soils of upland areas and also on inorganic soils of poorly-drained lowlands. Jack pine is widespread on well-drained gravel and sandy acid soils. On sites of undifferentiated glacial till, white spruce, balsam fir, white birch and trembling aspen are common tree species. A number of shrubs, herbs, bryophtes, and lichens are also common constituents of these forests. Bordering Hudson Bay is a forest-tundra section with patches of stunted trees, usually black or white spruce, and open tundra-like areas of lichen heath, fens and bogs. In addition, there are huge areas of swamp, fen, bog and muskeg. On better drained sites trees such as spruces, balsam fir, trembling aspen, balsam poplar, and white birch occur.

The soils in the northern part of the region, around Hudson Bay, are mostly Organic or Gleysolic. In the Canadian Shield there are many rock areas devoid of soil. Poorly drained areas contain peaty Gleysols as well as Organic soils. Most of the region, however, contains acid Podzols, and Brunisols with Luvisols in the old glacial lake beds. The thin, sandy Podzols and Brunisols are more sensitive to acidic precipitation than the clay-rich, moderately buffered Luvisols.

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